

# New Tool Released for Engine-Airframe Blade-Out Structural Simulations

Researchers at the NASA Glenn Research Center have enhanced a general-purpose finite element code, NASTRAN, for engine-airframe structural simulations during steady-state and transient operating conditions. For steady-state simulations, the code can predict critical operating speeds, natural modes of vibration, and forced response (e.g., cabin noise and component fatigue). The code can be used to perform static analysis to predict engine-airframe response and component stresses due to maneuver loads. For transient response, the simulation code can be used to predict response due to bladeoff events and subsequent engine shutdown and windmilling conditions. In addition, the code can be used as a pretest analysis tool to predict the results of the bladeout test required for FAA certification of new and derivative aircraft engines.

Before the present analysis code was developed, all the major aircraft engine and airframe manufacturers in the United States and overseas were performing similar types of analyses to ensure the structural integrity of engine-airframe systems. Although there were many similarities among the analysis procedures, each manufacturer was developing and maintaining its own structural analysis capabilities independently. This situation led to high software development and maintenance costs, complications with manufacturers exchanging models and results, and limitations in predicting the structural response to the desired degree of accuracy. An industry-NASA team was formed to overcome these problems by developing a common analysis tool that would satisfy all the structural analysis needs of the industry and that would be available and supported by a commercial software vendor so that the team members would be relieved of maintenance and development responsibilities. Input from all the team members was used to ensure that everyone's requirements were satisfied and that the best technology was incorporated into the code. Furthermore, because the code would be distributed by a commercial software vendor, it would be more readily available to engine and airframe manufacturers, as well as to nonaircraft companies that did not previously have access to this capability.

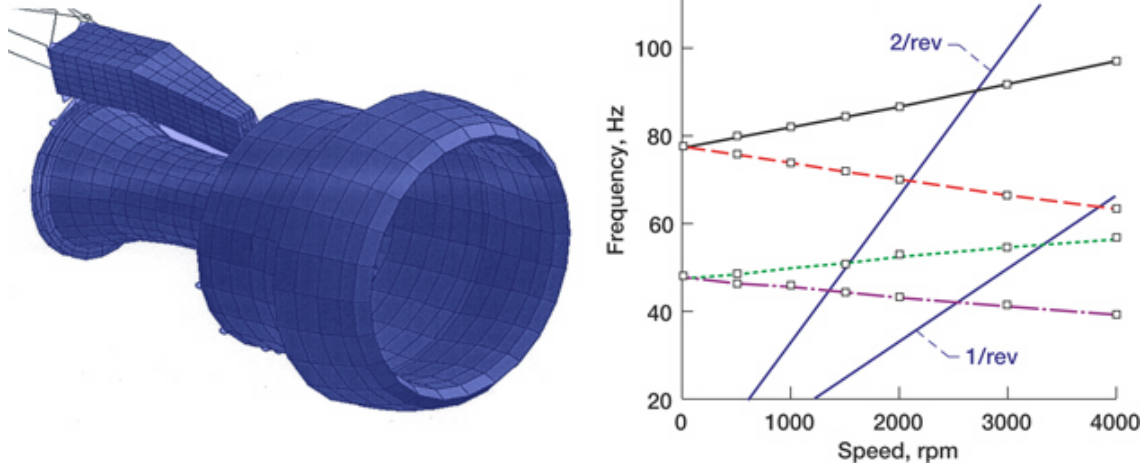
The development team included MSC.Software, the developer of the commercial finite element code NASTRAN. As part of this team activity, MSC.Software incorporated a wide spectrum of unique features and innovations for engine-airframe simulation into NASTRAN. A summary of these features follows:

1. *Multicomponent substructuring.* Engine-airframe structures are very large and complex, and they use finite element models often containing millions of degrees of freedom. Model reduction is required to practically implement these models for transient and steady-state analysis. The present code contains a full range of model-reduction capabilities that enables a large engine-airframe model to be condensed to a reduced-order model without sacrificing the accuracy contained in

the original full-fidelity model. The present code can reduce complex three-dimensional rotor models to simplified line models.

2. *Gyroscopic terms in steady-state and transient solutions.* The analysis of engine-airframe structures requires the incorporation of the rotational effects generated by the rotating turbomachinery. Gyroscopic terms were added into the equations of motion for the steady-state and transient response to include rotational effects in the analysis code. Spooldown and windmilling effects can be simulated because the engine rotational speed is allowed to vary with time. Rotor internal damping and gyroscopic effects also were included in static analysis so that the loads resulting from aircraft maneuvers could be computed.
3. *Multishaft systems.* Many aircraft engines, particularly larger size engines, consist of multishaft turbomachinery with each of the shafts rotating at different speeds. To accommodate this feature, the code incorporates the ability to model any number of spools, each rotating at arbitrary speeds.
4. *Sudden blade loss and spooldown effects.* The ability to model the transient loading that occurs during a blade loss event is incorporated in the code by allowing for multiple blade mass unbalances to be applied at locations along the rotor at different rotor angles and times. Spooldown effects that occur after the blade loss has occurred and the engine is shut down and begins a windmilling phase are incorporated by allowing for the rotational speed to be a nonconstant time-varying parameter. In addition to the unbalance load normally associated with a blade loss, the change in rotor inertia properties resulting from blade loss and damage can be included as a parametric disturbance to the system. This effect may lead to self-excited instabilities and additional loadings.
5. *Fan-case interaction models.* During a blade-off event, the large unbalance loads cause the rotor to exhibit large displacements that, in turn, cause the rotor blades to contact the casings. To model this occurrence, the code contains rub elements that apply a restoring force that pushes the rotor back into alignment and a friction force that opposes rotor rotation.

MSC.Software will market and distribute this version of NASTRAN worldwide. Every major commercial aircraft engine and airframe manufacturer in the world is committed to using this code. The new capabilities for rotating equipment simulation extend beyond aircraft structures and include applications in areas such as the automotive industry, space, military research and development, and power generation.



*Detailed blade-fan-case interaction model. Left: Aircraft engine finite element model.*

*Right: Natural vibration frequencies.*

Long description. Left: Model with grid. Right: Graph of frequency in hertz versus speed in revolutions per minute for modes 1 and 2 with forward and with backward whirl.

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